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Decomposing patterns of emission intensity in the EU and China: how much does trade matter?

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Abstract: This paper uses data from the World Input Output Database (WIOD) to examine channels through which CO2 emissions are embodied within and imported into the European production process. We apply a metric to calculate sectoral emission intensity and thus rank countries and sectors in the EU in terms of their emission intensity, and look at the evolution of patterns of emission intensity in 2005 and in 2009. We use an input-output price model to simulate the effect that a rise in the price of EU-ETS allowances, from $17 to $25 /tonne, would have on the final price of goods in each EU country and sector. We find that all countries in the EU reduced the emission-intensity of their production processes from 2005 to 2009, and we find that the reduction was greatest in those sectors regulated under the ETS. Comparisons of emission intensity between countries show that industries in Central and Eastern Europe are more emission intensive than those of Northern Europe, where industries import emission-intensive goods rather than producing them domestically. Finally we examine the trade in intermediate goods from China into the EU to examine possible increases in carbon leakage from 2005 to 2009. Results show that while emissions embodied in imported intermediate goods have increased from 2005 to 2009, this increase is not limited to, nor particularly notable in, the sectors regulated by the ETS.

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1 Introduction

The Kyoto protocol sets binding targets on international emission reductions. In order to meet the target of an 8% reduction in emissions by 2012, European countries adopted, as of 2005, a pricing scheme for their emissions, in order to curtail demand for emission-intensive goods. The Kyoto protocol was the only binding emissions-reduction target in place during the time period covered in our analysis; the EU's 20-20-20 targets we subsequently enacted in 2009. The climate policy web page of the European Commission states that: *"by putting a price on carbon and thereby giving a financial value to each tonne of emissions saved, the EU ETS has placed climate change on the agenda of company boards and their financial departments across Europe. A sufficiently high carbon price also promotes investment in clean, low-carbon technologies".* [1] The pricing scheme works as a cap on the total amount of emissions that can be produced, which is imposed on a group of "installations". Within the cap companies are allocated or can buy allowances to produce CO_2 emissions. In 2005 a number of free allowances were allocated through the operators. Companies can buy or sell allowances as required through the Emission Trading Scheme (ETS); the market for emission allowances determines the price of allowances. The sectors of the economy whose factories and installations are not regulated under ETS are bearing the costs of emission prices only indirectly: a change in the ETS allowance price will affect the costs of the sectors whose installations are under emissions regulation and thus the price of their goods, which can be used as intermediate inputs by other sectors of the economy. Identifying the patterns of sectoral emissions of EU countries is therefore a useful way to investigate whether ETS regulation has been effective in controlling emissions. As the Kyoto target assigns responsibility for emissions based on the production and not the consumption of goods, we also investigate the role of the trade in driving emissions across different European countries.

Our analysis is based on a number of different methods for investigating the emissions from production. The first one adopts an accounting perspective and uses macro-indicators of both sectoral emissions and sectoral production. This method allows us to identify the most emission-intensive sectors in European countries, and the relative contribution of these sectors to each country's GDP. The second method is based on an input-output methodology, which uses linear relationships between the sectors of each country to decompose sectoral emissions in the production system. Finally, we use an input-output price analysis to simulate the effect of a change in the ETS price from \$17 to \$25/tonne CO_2 [2] in both 2005 and 2009 in order to determine which sectors and which countries are impacted most by this measure.

There is a vast literature on embodied emissions. However, to our knowledge, the literature does not contain a single complete analysis of sectoral emissions for all EU countries in recent years. By examining

[1] `http://ec.europa.eu/clima/policies/ets/index_en.htm`
[2] All values in the WIOD are specified in US\$ and thus the simulated ETS prices are similarly represented in dollar terms

emission patterns for all countries in the EU and across 35 production sectors, our study makes an important contribution to the literature on the role played by trade in emission patterns. Our analysis provides new information which could be useful in the process of defining new emission targets.

The input-output model was originally proposed by Sraffa (1960), Pasinetti (1973), and Pasinetti (1988) among others. Subsequently, this method was extended to the analysis of greenhouse gas emissions by Treloar (1997) , Ferng (2003), Mongelli et al. (2006), Liang et al. (2007) and Butnar and Llop (2007). In particular, Sánchez-Chliz and Duarte (2004) and Machado et al. (2001) emphasize the role of trade in explaining the emission patterns of Spain and Brazil in 1995. Both papers highlight the role of trade as a source of emissions; in Spain the importing of goods that are used as intermediate inputs in construction and transport counts for 36% of the total emissions share. Emissions follow the opposite direction in Brazil, which exports emission-intensive goods that count for 14% of emissions. Tarancon et al. (2010) apply the input-output price analysis to investigate the influence of the manufacturing sector on electricity demand in Europe. We follow this approach to determine which countries and sectors will be most affected by a change in the price of emissions.

Our results show that European countries are characterized by very different patterns of emission production. In particular, Eastern Europe is the most emission-intensive region in both of the years analysed. Therefore, a rise in the ETS price will strongly affect these countries as their levels of emissions are the highest in Europe. At the same time, countries in this region have seen the largest reduction in emission-intensity from 2005 to 2009. We also find that the reduction of emission intensities in Eastern European countries was associated with a decrease in the economic importance of the emission-intensive sectors. Thus it is possible to hypothesize that part of the emission-intensive production has been shifted from these countries to other non-European countries where no price is placed upon emissions, i.e., that carbon leakage may be occurring.

To analyse the hypothesis that the reduction of emission intensity in Europe is as a result of emissions being displaced rather than a genuine reduction in the quantity of carbon embodied in goods, we investigate whether the quantity of inputs used in the production process that are imported from China has increased. Other studies, such as Shimoda et al. (2008), find that increases in emissions in China are being partially driven by consumption in other countries. Furthermore research by Lin and Sun (2010) has found that emissions from production in China are greater than its consumption-based emissions which, the authors state, highlights that carbon leakage is occurring and indicates the current framework for addressing climate change is inadequate. Our results also show a significant increase in the level of imported embodied emissions from China into the EU between 2005 and 2009, but we do not find that this pattern is particular to sectors regulated under ETS.

The rest of the paper is organised as follows. Section 2 describes the database used in the analysis and

Section 3 presents the two methods used to decompose sectoral emissions. Section 4 analyses the production of emission-intensive goods for export and presents the results of the price analysis. Section 5 presents an analysis of trade in intermediate goods from China to the EU. At the end of the paper we provide some concluding remarks.

2 Data description

The emission data and the input-output tables used in our analysis are from the World Input-Output Database (WIOD: www.wiod.org). This database contains input-output tables and environmental accounts (which includes CO_2 emissions) for 27 EU countries and 13 other major countries in the world between 1995 and 2009. The input-output tables and the emission data are presented at a 35-sector level of aggregation. While data are available for all years up until 2009, we have chosen to focus on 2005 and 2009 in our analysis so that we could compare patterns of emissions and economic activity before and after the EU ETS was implemented. Our analysis focuses on the 27 countries of the EU and on China, and we consider the emissions of CO_2 only. There are a number of data caveats in the WIOD. CO_2 emissions for certain countries are reported as zero in some sectors where it is unlikely that no CO_2 was emitted (for example, in certain transport sectors in Malta). Details of the methodologies and data sources used to construct the economic tables and the environmental accounts can be found in Genty and Neuwahl (2012) and Timmer (2012); in particular further data caveats are discussed by Timmer (2012). Table 1 shows the sectors that are, on average, in the last decile of the distribution of emission intensity in the EU in 2005 and 2009 respectively. The pattern of emission intensity is relatively stable between the two years considered.

Table 1: Emission intensity, highest decile of the distribution, 2005 & 2009

2005	2009
Other Air Transport	Chemicals and Chemical Products
Chemicals and Chemical Products	Coke, Refined Petroleum and Nuclear Fuel
Coke, Refined Petroleum and Nuclear Fuel	Basic Metals and Fabricated Metal
Other Inland Transport	Other Air Transport
Basic Metals and Fabricated Metal	Other Non-Metallic Minerals
Other Non-Metallic Minerals	Other Inland Transport
Electricity, Gas and Water Supply	Electricity, Gas and Water Supply

3 Methodology

Our analysis can be divided into four parts: first we use statistical indicators to quantify the economic importance of the emission-intensive sectors. Second, we use details provided by the input-output tables to look at export patterns of emission-intensive goods. Third, we use the Leontief matrix derived from the input-output analysis to assess the impact of a change in the emission price on the different sectors of each of the 27 EU countries. Finally, we use inter-regional input-output tables and environmental accounts to quantify the embodied emissions of Chinese intermediate goods exported to Europe. We examine how these embodied emissions have changed from 2005 to 2009.

3.1 Statistical indicators

We follow Mendiluce et al. (2010) and Alcántara and Duarte (2004) to calculate the energy intensity of the economy. We distinguish between the 35 sectors of the economy ($s = 1, .., 35$) and the 27 EU countries ($i = 1, .., 27$). The energy intensity indicator is described by the following Equation:

$$\frac{E_i}{Y_i} = \sum \frac{E_{s,i}}{Y_{s,i}} \frac{Y_{s,i}}{Y_i} \qquad (1)$$

The left term in Equation 1 is the emission intensity in country i, calculated as the ratio between the emissions of country i (E_i) and its GDP (Y_i). The first term on the right side of Equation 1 is the sectoral emission intensity. The ratio ($\frac{E_{s,i}}{Y_{s,i}}$) shows the emissions in the s sector of country i divided by sectoral GDP, and the term $\frac{Y_{s,i}}{Y_i}$ measures how much sector s contributes to country i's GDP. Thus the indicator allows emission intensity to be decomposed into sectoral emission intensity and output intensity.

3.2 Input Output decomposition and price analysis

3.2.1 Input output decomposition

Having examined the emission intensity of EU countries, we then use the details of the production structure of each economy, as given in the national input-output tables, to decompose sectoral emissions into those which are driven by internal and external demand. The emission-intensive sectors vary across Europe. We identify three groups of countries (Northern European, Mediterranean and Eastern European countries) in order to find similarities in the emission patterns in 2005 and in 2009. The main assumption behind the input-output model is that, for each year, each industry consumes the output of other industries in a fixed ratio, in order to produce its output. We apply the same methodology to 2005 and 2009 and then we compare the results. We follow the price model outlined in Tarancon et al. (2010). The basic equation that describes the linear relationships between the sectors of each country is:

$$x = Ax + \gamma \tag{2}$$

Where x is the total output required, γ is the final demand/consumption and A is the matrix of technological coefficients (a_{ij}), that represent the input required by another sector to produce a unit of monetary output. Thus, Ax is the n-vector of intermediate demand, and

$$a_{ij} = \frac{x_{ij}}{x_i} \tag{3}$$

Solving for x leads to:

$$x = (I - A)^{-1}\gamma \tag{4}$$

Where I is the identity matrix and $(I - A)^{-1}$ is the Leontief inverse matrix. The environmental extension of the basic IO model described by Equation 4 can be obtained by multiplying the Leontief matrix by the environmental matrix E, which contains the emission coefficients, i.e., CO_2 emitted by each sector to produce one unit of output. [3]

$$M = E(I - A)^{-1}\gamma \tag{5}$$

In which M gives the total (direct and indirect) CO_2 emissions of each sector.

The input-output tables provide information on the amount of final output (γ) which is used to satisfy demand from abroad. We use this information on exports to examine whether some countries export more emission-intensive goods than others.

3.2.2 Price model

The input-output model allows us to simulate the effects of a change in the ETS price on the productive sectors. We identify the changes in the cost of different sectors as a result of the changes in the value of the energy inputs. Specifically, we investigate the effects of a rise in the ETS allowance price from \$17 to \$25 /tonne, both in 2005 and in 2009. We apply exactly the same change in the ETS price in both years in order to compare the results. Under the ETS certain factories/installations are regulated. The input-output table does not provide information at this level of detail, so we make the simplifying assumption that the following sectors are regulated:

We assume that all the other sectors pay a carbon tax equal to \$1/t CO_2 that is kept constant over time

[3] The environmental matrix has been widely used in literature. See, among others Treloar (1997), Lenzen (1998),Machado et al. (2001), Ferng (2003), Alcántara and Duarte (2004), Sánchez-Chliz and Duarte (2004), Mongelli et al. (2006), Liang et al. (2007) and Butnar and Llop (2007)

Table 2: Sectors regulated under ETS

Mining and Quarrying
Pulp, Paper, Printing and Publishing
Coke, Refined Petroleum and Nuclear Fuel
Chemicals and Chemical Products
Non-Metallic Minerals
Basic Metals and Fabricated Metal
Electricity, Gas and Water Supply

in order to disentangle the effects of the change in the ETS price only. Changing the allowance price will have a direct effect on the sectors regulated under the ETS, and an indirect effect on the prices of the sectors not directly regulated by the ETS. This indirect effect can be interpreted as an indicator of the pressure that the cost functions of different sectors bear as a result of the increase in the prices of the emissions, and thus of the energy inputs, given the chain of the productive relationships captured by the input-output system. The value of the output of country i and sector s will be equal to the value of the intermediate consumption and the value of the primary inputs (such as wages, taxes and energy). This relation can be expressed as:

$$x^q_{s,i} p_{x_{i,s}} = a_{1,i,s} x^q_{i,s} p_{x_{1,i}} + a_{2,i,s} x^q_{i,s} p_{x_{2,i}} + ... + a_{n,i,s} x^q_{i,s} p_{x_{n,i}} + z^q_{i,s} p_{z_{s,i}} \tag{6}$$

where z is the vector of the primary inputs, p refers to the prices and x refers to physical units. Dividing the previous equation by the physical output leads to:

$$p_{x_{i,s}} = a_{1,i,s} p_{x_{1,i}} + a_{2,i,s} p_{x_{2,i}} + ... + a_{n,i,s} p_{x_{n,i}} + \delta p_{z_{s,i}} \tag{7}$$

in which $\delta_{s,i}$ is the ratio between the primary input of the sector s and its output, and $p_{x_{i,s}}$ is the price of the goods produced by sector s. Initially, all these prices will be assumed equal to 1. Prices of goods and services produced by sector s of each country can be related to the changes in the prices of primary inputs. In particular, in this paper we assume that the only change in the primary input prices will be the change in the emission price, which affects the cost of energy. We can calculate the variation of the final prices after the change in the ETS price with the following:

$$p_{x_{i,s}} = \sum_{q=1}^{n} l_{qs,i} \delta q \tag{8}$$

where $l_{qs,i}$ is the element of the column s of the Leontief matrix of the country i. The emission intensity of each sector will determine the impact of the variation of the ETS price on that sector's price; moreover, through the relations described by the input-output tables, the change of the price of the sector s will generate variations in the price of other goods. Emission-intensive sectors or sectors that use emission-intensive goods as intermediate inputs will experience greater increases in their final costs relative to the low-emission sectors, or sectors that do not use emission-intensive intermediates.

4 Results

4.1 Emission intensity

The emission-intensity indicator described by Equation 1 may be used to compare the sectoral emissions of each country. Our analysis shows that all the Eastern European countries have higher levels of emission intensity compared to Northern and Mediterranean European countries. However, the ratio of sectoral emissions to total GDP experienced a stronger contraction in the Eastern European countries than in the other regions between 2005 and 2009, as shown in Table 3.

Table 3: Total emission intensity, 2005 & 2009

	2005	2009	% decline
UK	0.112	0.105	1.586
Ireland	0.079	0.057	8.437
Germany	0.137	0.108	6.303
France	0.076	0.055	8.446
Sweden	0.073	0.063	3.804
Austria	0.100	0.067	10.392
Belgium	0.128	0.094	8.115
Finland	0.146	0.118	5.586
Luxembourg	0.038	0.022	14.998
Netherlands	0.140	0.109	6.458
Denmark	0.171	0.143	4.474
Spain	0.131	0.079	13.387
Italy	0.112	0.082	8.197
Cyprus	0.255	0.179	9.231
Greece	0.252	0.192	7.097
Malta	0.201	0.157	6.323
Portugal	0.180	0.120	10.583
Estonia	0.503	0.382	7.120
Slovakia	0.349	0.170	19.672
Slovenia	0.183	0.136	7.738
Poland	0.471	0.318	10.366
Romania	0.490	0.246	18.841
Bulgaria	0.786	0.392	18.951
Czech Rep.	0.341	0.209	13.069
Hungary	0.204	0.159	6.435
Latvia	0.221	0.141	11.821
Lithuania	0.280	0.181	11.529

The results of the Eastern European countries are particularly interesting, as they highlight that the production of emission-intensive goods contracted strongly from 2005 to 2009. We separate the ETS from the non-ETS sectors to see whether sectors under emission-price regulation perform differently vis-à-vis other sectors. Table 4 shows the emission and output intensities of the ETS-regulated sectors.

Table 4: Emission intensity ($\frac{E_{s,i}}{Y_{s,i}}$) and output intensity ($\frac{Y_{s,i}}{Y_i}$) in ETS sectors, 2005 & 2009

	Emission Intensity			Output Intensity		
	2005	2009	% change	2005	2009	% change
UK	0.014	0.011	5.527	6.25%	5.52%	0.007
Ireland	0.012	0.007	13.458	8.36%	7.67%	0.007
Germany	0.015	0.012	6.248	8.24%	7.46%	0.008
France	0.019	0.013	10.170	8.78%	8.58%	0.002
Sweden	0.016	0.014	4.137	9.64%	9.22%	0.004
Austria	0.022	0.016	7.256	9.77%	9.26%	0.005
Belgium	0.026	0.018	9.038	9.70%	8.76%	0.009
Finland	0.031	0.023	8.170	14.44%	12.24%	0.022
Luxembourg	0.011	0.006	16.477	3.69%	2.63%	0.011
Netherlands	0.023	0.016	8.802	9.48%	8.83%	0.007
Denmark	0.017	0.011	11.572	8.20%	6.75%	0.014
Spain	0.096	0.053	16.163	14.45%	13.66%	0.008
Italy	0.074	0.052	9.472	14.99%	13.79%	0.012
Cyprus	0.178	0.132	7.771	8.65%	8.73%	**-0.001**
Greece	0.188	0.136	8.519	11.92%	11.00%	0.009
Malta	0.149	0.122	5.205	9.98%	10.96%	**-0.010**
Portugal	0.118	0.075	11.992	13.45%	14.20%	**-0.008**
Estonia	0.448	0.334	7.621	11.21%	33.42%	**-0.222**
Slovakia	0.267	0.133	18.990	21.65%	13.31%	0.083
Slovenia	0.130	0.086	10.812	16.78%	8.63%	0.081
Poland	0.371	0.243	11.122	17.11%	24.30%	**-0.072**
Romania	0.352	0.172	19.570	18.73%	17.24%	0.015
Bulgaria	0.645	0.318	19.312	22.07%	31.84%	**-0.098**
Czech Rep.	0.277	0.171	12.897	18.31%	17.07%	0.012
Hungary	0.122	0.093	7.119	15.05%	9.28%	0.058
Latvia	0.099	0.057	14.656	8.95%	5.70%	0.033
Lithuania	0.179	0.110	13.021	19.60%	10.97%	0.086

As table 4 shows, Eastern EU countries had the strongest reduction in emission intensity in the ETS sectors. Moreover, the decline in the emission-intensity of the ETS sectors happened concurrently with a reduction in output intensity. The particularly large contraction of emission intensity in the ETS-regulated sectors suggests this reduction can be partially attributed to the ETS, adopted in 2005. However, the change in output intensity highlights that the production intensity of the more polluting sectors has decreased between 2005 and 2009. This implies that the production of CO_2-intensive goods seems to have shifted from the Eastern European countries to other countries outside the EU.

4.2 Sectoral analysis and ETS impact

The results of our analysis on emissions intensity have shown the heterogeneity of different EU countries. It is important to analyze whether the introduction of ETS in 2005 has changed the performance of the ETS sectors (shown in Table 2) with respect to the other sectors of the economy [4]. The first part of the indicator expressed in Equation 1 (the ratio $\frac{E_{s,i}}{Y_{s,i}}$) reflects the sectoral emission intensities across different countries. Thus, we use this indicator to evaluate the sectoral emission intensity of each country in 2005 and in 2009 and compare them. Table 5 shows the average of the differences in the emission intensities between 2005 and 2009 for the EU countries. Column 1 reports the averages for the sectors directly affected by ETS regulation and Column 2 shows the average of the change in emission intensities for all other sectors.

Table 5: Differences in the average emission intensity ($ktCO_2$/m$), 2005 & 2009; ETS vs other sectors

	Countries	ETS sector average	Non-ETS sector average
	EU	-0.42	-0.34
Northern/Central	GB	-0.21	-0.10
	IE	-0.44	-0.39
	Germany	-0.34	-0.37
	France	-0.58	-0.43
	Sweden	-0.23	-0.30
	Austria	-0.49	-0.76
	Belgium	-0.51	-0.67
	Finland	-0.55	-0.39
	Luxembourg	-1.36	-1.25
	NLD	-0.57	-0.29
	Denmark	-0.46	-0.28
Medit	Spain	-0.75	-0.47
	Italy	-0.47	-0.32
	Cyprus	-0.49	-0.73
	Greece	-0.59	-0.44
	Malta	0.20	-0.48
	Portugal	-0.46	-0.43
Eastern	Estonia	-0.86	-0.08
	Slovakia	-0.98	-1.43
	Slovenia	-1.27	-0.88
	Poland	-0.46	-0.44
	Romania	-1.80	-2.17
	Bulgaria	-3.63	-0.76
	CHZ	-0.66	-0.91
	Hungary	-0.33	-0.82
	Latvia	-0.78	-0.94
	Lithuania	-0.69	-0.55

As shown in Table 5, sectors directly affected by ETS have reduced their emission intensity between 2005

[4] In this section of the paper we focus on the ratio between sectoral emissions and sectoral GDP as the statistical analysis gives an immediate measure of the impact of the emission price on sectoral emissions and can be useful to present the different country specificities. As the increase of the ETS will affect also the final prices of the different sectors through direct and indirect effects we will present a detailed analysis of the effects of the variation of the ETS on the economy in Section 4.3.2

to 2009 more than the other sectors. In particular, Eastern European countries show the greatest change in the emission-intensity patterns. There are two factors that explain the reduction in emission intensity in Eastern EU. On one hand the GDP of countries in Eastern Europe has grown quite rapidly from 2005 and 2009; thus the denominator of the emission-intensity indicator has increased. On the other hand, the emissions, in absolute terms, have decreased for all the EU countries, including the Eastern countries. This second effect may be influenced by the adoption of the emissions-pricing scheme, and by the relocation of the production of highly emission-intensive goods to other countries (such as China). However, the data used in this analysis do not allow us to fully identify these two effects. Thus, in order to give a partial explanation of the latter effect, in Section 5 we analyse the imports of goods (and thus, embodied emissions) from China.

4.3 Decomposition analysis

The results of the statistical analysis show that the ratio of sectoral emissions to each country's GDP fell between 2005 and 2009. Moreover, our results show that, on average, the ratio between sectoral emissions and sectoral GDP has fallen more in the sectors regulated by ETS pricing compared to other sectors of the economy. This result emphasizes that the ETS, adopted by the EU, may have changed the behavior of the sectors directly affected by the emission prices [5]. Our results show that EU countries are reducing the quantity of CO_2 emitted in the production of various goods, as they are committed to do according to the Kyoto protocol. However, our analysis also highlights that different emission patterns emerge across the EU. As the responsibility for emissions is assigned based on the production of goods in different sectors, it is interesting to determine whether relatively non-polluting countries are importing emission-intensive goods from the more emission-intensive countries. It is also worth analysing the extent to which the EU as a whole is importing more CO_2-intensive goods from other countries in the world and, in particular, from China.

The following paragraphs aim to answer these questions. First, we investigate whether Eastern Europe, as the most emission-intensive region, consistently exports a larger part of its production from sectors classified (see Table 1) as highly emission-intensive, relative to the rest of the EU. Second, we examine the impact of a simulated change in the price of ETS allowances.

Finally, we analyze the trade dynamics between Europe and China in order to establish the amount of emission-intensive goods produced in China which are used by European countries in their production processes.

[5] The data available for our analysis do not allow us to disentangle the reasons behind the fall in emissions. Falling emissions may be attributed to the adoption of the ETS pricing, but other factors may have simultaneously been driving a decline in the overall production of emission-intensive goods

4.3.1 I/O analysis: exports

Table 6 shows the percentage of goods exported by countries of the same geographical area (Northern, Mediterranean and Eastern) by sector and year. The column "Δ" gives the difference between the percentage of goods exported between 2005 and 2009.

Our results show that the net exports from sectors that, according to Table 1, may be classified as more emission intensive, are higher in the Eastern European countries compared to the rest of the EU, both in 2005 and 2009. Furthermore, the Δ column shows that while the exports from these sectors fell in Northern EU countries, and to a lesser extent in Mediterranean countries, from 2005 to 2009, they increased in Eastern EU countries.

This suggests that while, on average, the production of more CO_2-intensive goods for export has decreased in the EU over time, the more emission-intensive production is more concentrated in a specific region of Europe. Thus, the UNFCCC definition of environmental responsibility, which assigns responsibility for emissions to the producer and not to the consumer, penalizes Eastern countries more than Northern European countries. Thus, a target based on consumption instead of one based on production would be required to correctly assign the emissions to the countries that demand and consume the emission-intensive goods.

The same issue arises when the trade between Europe and China is examined. Our analysis shows that, according to the emission-accounting methodology of the Kyoto protocol, European industries have succeeded in reducing their emission intensity, as the production of CO_2-intensive goods decreased between 2005 and 2009. However, as will be discussed in Section 5, the production of emission-intensive goods may have just shifted from Europe to China. The emissions embedded in the intermediate inputs or final goods imported from China are not not captured by the current emissions trading scheme.

Table 6: I/O decomposition analysis - proportion of output produced for export (2005 & 2009)

	Northern			Mediterranean			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
ETS Sectors:									
Mining and Quarrying	11.68%	12.30%	**0.62%**	5.19%	5.76%	**0.57%**	0.71%	5.02%	**4.31%**
Pulp, Paper, Printing and Publishing	16.80%	15.61%	-1.19%	6.54%	7.89%	**1.35%**	14.72%	14.19%	-0.54%
Coke, Refined Petroleum and Nuclear Fuel	24.47%	20.27%	-4.20%	15.57%	12.21%	-3.36%	11.03%	18.64%	**7.61%**
Chemicals and Chemical Products	34.07%	32.79%	-1.28%	16.39%	15.08%	-1.30%	32.39%	32.77%	**0.39%**
Other Non-Metallic Minerals	13.08%	10.56%	-2.52%	11.10%	8.84%	-2.26%	17.33%	15.50%	-1.84%
Basic Metals and Fabricated Metal	28.39%	25.74%	-2.65%	13.05%	13.21%	**0.16%**	33.54%	28.70%	-4.84%
Electricity, Gas and Water Supply	8.37%	7.58%	-0.79%	0.92%	1.29%	**0.37%**	6.66%	8.70%	2.04%
Non-ETS Sectors:									
Agriculture	12.17%	12.28%	**0.11%**	10.59%	9.95%	-0.64%	12.01%	15.34%	**3.33%**
Food, Beverages and Tobacco	17.33%	17.15%	-0.19%	8.77%	10.05%	**1.28%**	9.81%	11.69%	**1.88%**
Textiles and Textile Products	14.70%	11.95%	-2.75%	16.45%	14.43%	-2.02%	29.90%	23.96%	-5.94%
Leather, Leather and Footware	2.46%	2.16%	-0.30%	7.21%	6.22%	-0.99%	10.20%	8.20%	-2.00%
Wood and Products of Wood and Cork	8.57%	7.44%	-1.13%	4.94%	3.97%	-0.98%	16.14%	13.32%	-2.82%
Rubber and Plastics	14.84%	12.86%	-1.97%	9.45%	9.21%	-0.24%	12.82%	16.26%	**3.44%**
Machinery, NEC	12.44%	12.41%	-0.03%	10.30%	10.93%	**0.63%**	18.89%	18.60%	-0.30%
Electrical and Optical Equipment	10.18%	9.82%	-0.36%	5.66%	10.22%	**4.56%**	18.38%	20.78%	**2.41%**
Transport Equipment	7.97%	7.63%	-0.35%	10.08%	8.76%	-1.32%	20.94%	16.62%	-4.32%
Manufacturing, NEC; Recycling	11.34%	10.92%	-0.42%	7.49%	6.73%	-0.76%	19.65%	17.57%	-2.09%
Construction	0.42%	0.36%	-0.06%	0.12%	0.14%	**0.02%**	0.84%	0.80%	-0.04%
Sale of Motor Vehicles and Motorcycles	1.03%	1.26%	**0.23%**	1.69%	1.19%	-0.49%	3.15%	3.93%	**0.78%**
Wholesale Trade and Commission Trade	1.67%	1.47%	-0.20%	0.95%	0.69%	-0.26%	1.47%	1.77%	**0.30%**
Retail Trade	0.22%	0.69%	**0.46%**	0.54%	0.43%	-0.11%	1.17%	1.24%	**0.07%**
Hotels and Restaurants	2.01%	2.18%	**0.17%**	3.61%	3.63%	**0.02%**	2.76%	2.48%	-0.28%
Other Inland Transport	7.98%	8.66%	**0.68%**	9.13%	8.84%	-0.29%	23.27%	24.20%	**0.93%**
Other Water Transport	20.41%	19.58%	-0.83%	19.06%	18.16%	-0.90%	6.49%	7.17%	**0.69%**
Other Air Transport	12.63%	13.16%	0.53%	9.25%	11.00%	**1.75%**	11.74%	10.50%	-1.24%
Supporting Transporting Activities	1.72%	1.68%	-0.03%	1.48%	1.30%	-0.18%	3.37%	3.08%	-0.29%
Post and Telecommunications	1.71%	2.24%	**0.52%**	0.42%	0.40%	-0.02%	1.65%	2.33%	**0.69%**
Financial Intermediation	1.08%	1.44%	**0.35%**	0.19%	0.14%	-0.05%	0.74%	0.69%	-0.05%
Real Estate Activities	0.01%	0.01%	0.00%	0.00%	0.00%	0.00%	0.12%	0.08%	-0.04%
Renting of Machinery and Equipment	1.44%	1.15%	-0.29%	1.33%	0.79%	-0.54%	1.60%	1.53%	-0.07%
Public Admin	0.50%	0.41%	-0.09%	0.21%	0.22%	**0.01%**	0.62%	0.54%	-0.08%
Education	0.47%	0.47%	-0.01%	0.16%	0.16%	0.00%	0.22%	0.19%	-0.03%
Health and Social Work	0.10%	0.09%	0.00%	0.19%	0.19%	0.00%	0.53%	0.83%	**0.30%**
Social and Personal Services	3.61%	3.55%	-0.06%	0.71%	0.54%	-0.17%	2.13%	2.64%	**0.51%**
Average ETS sectors			-1.72%			-0.64%			**1.02%**
Average non-ETS sectors			-0.22%			-0.06%			-0.15%

Note: Figures in bold highlight the sectors in which the percentage of exports in total production has increased from 2005 to 2009

4.3.2 Effects of ETS price variation

Our previous results show that the production of emission-intensive goods is not evenly located across Europe; therefore, the impact of a rise in the ETS price will have heterogenous effects across the EU. We use Equation 8 to determine the impact of a change in the emission price on different countries and different sectors. Table 7 shows the results for the sectors under ETS regulation, and Table 8 shows the results for all the other sectors, that are indirectly affected by the ETS price increase. These tables show that, as expected, ETS-regulated sectors are more strongly affected by the price variations than all other sectors, that bear the cost of the ETS price increase only indirectly. Given the higher levels of CO_2 emitted in their production process, the Eastern European countries are affected more by the ETS price change than the other European countries, both in 2005 and in 2009.

Note that we are simulating an identical price increase in the ETS-regulated sectors in both years. Therefore, what the following tables are showing is that the effect of an increase in the price of allowances is less strong in 2009, compared to 2005 (as shown in the Δ column), reflecting the general decarbonisation of the European production sector over this period.

Table 7: Final price change after the variation of ETS price, ETS-regulated sectors (2005 & 2009)

	Northern			Mediterranean			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
Mining and Quarying	0.27%	0.22%	-0.05%	1.01%	1.02%	**0.01%**	0.64%	0.38%	-0.26%
Pulp, Paper, Printing and Publishing	0.12%	0.10%	-0.02%	0.22%	0.16%	-0.06%	0.39%	0.21%	-0.18%
Coke, Refined Petroleum and Nuclear Fuel	0.33%	0.29%	-0.04%	0.25%	0.39%	**0.14%**	1.20%	1.22%	**0.01%**
Chemicals and Chemical Products	0.17%	0.12%	-0.05%	0.28%	0.19%	-0.10%	1.19%	0.63%	-0.56%
Other Non-Metallic Minerals	0.79%	0.61%	-0.17%	1.25%	0.91%	-0.34%	1.71%	1.09%	-0.62%
Basic Metals and Fabricated Metal	0.29%	0.22%	-0.07%	0.43%	0.73%	**0.30%**	0.84%	0.43%	-0.41%
Electricity, Gas and Water Supply	1.53%	1.11%	-0.42%	3.04%	1.98%	-1.06%	4.61%	2.65%	-1.96%

Table 8: Final price change after the variation of ETS price, sectors not regulated under ETS (2005 & 2009)

	Northern			Mediterranean			Eastern		
	2005	2009	Δ	2005	2009	Δ	2005	2009	Δ
Agriculture, Hunting, Forestry and Fishing	0.05%	0.04%	-0.01%	0.11%	0.08%	-0.02%	0.15%	0.10%	-0.05%
Food, Beverages and Tobacco	0.04%	0.03%	-0.01%	0.14%	0.11%	-0.03%	0.21%	0.13%	-0.08%
Textiles and Textile Products	0.04%	0.03%	-0.01%	0.14%	0.09%	-0.04%	0.18%	0.11%	-0.07%
Leather, Leather and Footware	0.03%	0.02%	-0.01%	0.11%	0.09%	-0.02%	0.16%	0.09%	-0.07%
Wood and Products of Wood and Cork	0.05%	0.04%	-0.01%	0.11%	0.09%	-0.02%	0.21%	0.13%	-0.07%
Rubber and Plastics	0.05%	0.04%	-0.01%	0.18%	0.14%	-0.04%	0.23%	0.12%	-0.10%
Machinery, NEC	0.05%	0.04%	-0.01%	0.11%	0.10%	-0.02%	0.25%	0.14%	-0.10%
Electrical and Optical Equioment	0.03%	0.02%	-0.01%	0.09%	0.08%	-0.01%	0.15%	0.09%	-0.07%
Transport Equipment	0.04%	0.03%	-0.01%	0.14%	0.11%	-0.03%	0.20%	0.12%	-0.09%
Manufacturing, nec; Recycling	0.05%	0.04%	-0.01%	0.10%	0.09%	-0.02%	0.19%	0.12%	-0.07%
Construction	0.06%	0.05%	-0.01%	0.21%	0.15%	-0.06%	0.22%	0.12%	-0.10%
Sale of Motor Vehicles and Motorcycles	0.03%	0.02%	-0.01%	0.11%	0.07%	-0.04%	0.14%	0.10%	-0.04%
Wholesale Trade and Commission Trade	0.03%	0.02%	-0.01%	0.09%	0.06%	-0.03%	0.11%	0.07%	-0.05%
Retail Trade	0.03%	0.03%	-0.01%	0.10%	0.06%	-0.03%	0.17%	0.10%	-0.07%
Hotels and Restaurants	0.04%	0.03%	-0.01%	0.14%	0.10%	-0.05%	0.19%	0.12%	-0.07%
Other Inland Transport	0.03%	0.02%	-0.01%	0.09%	0.07%	-0.03%	0.17%	0.11%	-0.06%
Other Water Transport	0.02%	0.02%	0.00%	0.06%	0.04%	-0.02%	0.11%	0.08%	-0.04%
Other Air Transport	0.03%	0.02%	0.00%	0.08%	0.05%	-0.02%	0.13%	0.09%	-0.04%
Supporting Transporting Activities	0.03%	0.02%	0.00%	0.11%	0.08%	-0.03%	0.14%	0.09%	-0.05%
Post and Telecommunications	0.02%	0.02%	-0.01%	0.06%	0.06%	0.00%	0.10%	0.07%	-0.04%
Financial Intermediation	0.02%	0.01%	0.00%	0.06%	0.04%	-0.02%	0.08%	0.06%	-0.02%
Real Estate Activities	0.02%	0.02%	0.00%	0.05%	0.03%	-0.02%	0.22%	0.13%	-0.09%
Renting of Machinery and Equipment	0.02%	0.01%	0.00%	0.06%	0.04%	-0.02%	0.13%	0.07%	-0.06%
Public Admin	0.03%	0.02%	0.00%	0.09%	0.07%	-0.02%	0.15%	0.08%	-0.08%
Education	0.02%	0.02%	-0.01%	0.05%	0.04%	-0.01%	0.20%	0.11%	-0.09%
Health and Social Work	0.02%	0.02%	-0.01%	0.06%	0.04%	-0.02%	0.19%	0.10%	-0.09%
Social and Personal Services	0.03%	0.03%	-0.01%	0.12%	0.09%	-0.04%	0.23%	0.13%	-0.09%
Private Households with employed persons	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%

5 Exports from China and embodied CO_2 emissions

The analysis to this point suggests that in general all regions of Europe are reducing the emission intensity of their production processes; and that this is particularly true for those sectors regulated under the EU-ETS. This is an important and positive finding if industries within the region are embracing more environmentally-friendly production processes, however it is also possible that we are seeing a reduction in the emission-intensity of production due to carbon leakage. Helm et al. (2007), looking at this issue for the UK, has stressed that a country could produce low-carbon-intensity goods but import and consume goods that are highly carbon-intensive. According to the current UNFCCC methodology such a country would have low carbon intensity. Helm estimates that, in the UK, consumption-based emissions have risen by 19% from 1990-2003; this is in stark contrast to the *reduction* in emissions it has achieved according to the UNFCCC methodology, which accounts only for emissions from production. A large part of the fall in productive emissions experienced by the UK has been as a result of the changing structure of production away from energy- and emission-intensive goods, many of which are now imported from China, India and other developing countries. In this part of our analysis we wish to examine whether the same pattern holds for production at a European level, with a focus on intermediate goods, i.e. goods that are used as inputs in the production process. It is possible that the reduction which we have seen in emission intensity across Europe has been a result of firms choosing to import carbon-intensive intermediate goods from China rather than producing them domestically.

Of course the EU has many trading partners besides China but our decision to focus on intermediate goods from China was motivated by the fact that over the period of our analysis there has been a notable increase in the amount of intermediate goods used in the European production process that come from China. According to the WIOD, from 2005 to 2009 the value of Chinese intermediates used in the EU production process has increased by 158%; this is in contrast to an increase of 16% and 10% in the value of intermediates imported from the NAFTA [6] and BRIIAT [7] regions respectively, and a reduction of 8% in the value of intermediates imported from East Asia.

5.1 Patterns of emission intensity: Europe and China

The graph below illustrates the relative emissions intensity in Europe and China for the ten most polluting sectors in China, in 2005 and 2009; it shows that the Chinese economy is significantly more emission intensive than that of Europe, but that both regions have achieved reductions in emission intensity in recent years. Emission intensity is calculated as sectoral CO_2 emissions divided by sectoral output.

[6] North American Free Trade Agreement

[7] Brazil, Russia, India, Indonesia, Australia and Turkey

Figure 1: Emission intensity of output 2005 and 2009: EU and China

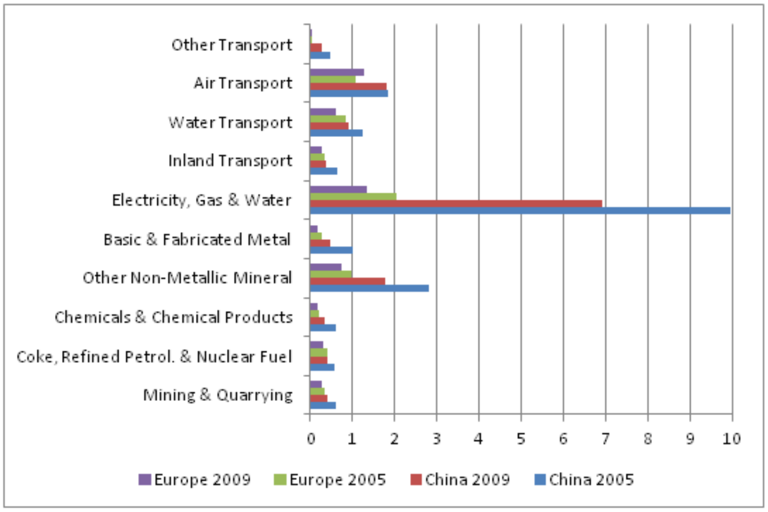

Figure 1 shows that while both regions are reducing the carbon intensity of production, the level of carbon intensity in China remains far above that of Europe; this implies that if intermediate goods, previously produced in Europe, are now being produced in China, global CO_2 emissions driven by the European production process will have risen in a way that is not captured by the producer-pays definition of environmental responsibility. The producer-pays principle would attribute these emissions to China, whereas a consumer-pays definition of environmental responsibility would attribute responsibility for these emissions to European industries.

Furthermore, Figure 1 shows that using a single region input-output analysis to approximate the embodied emissions imported into Europe from China would lead to a significant under-counting of embodied emissions, as the Chinese production process is much more emission-intensive than that of the EU.

5.2 Embodied emissions

To examine the quantity of intermediate goods that are used in the European production process but produced in China we make use of the Interregional Input-Output tables, available via the World Input-Output Database. We combined data from the Eurozone and "Other EU" countries to look at the quantity of Chinese inputs used in the total EU production process. This allows us to look at the proportion of inputs used in each sector that come from China, and thus quantify the imported emissions embodied in the European production process.

Figure 2: The proportion of European inputs sources from China, 2005 and 2009

	2005	2009
Agriculture, Hunting, Forestry and Fishing	0.32%	0.70%
Mining and Quarrying	0.46%	1.05%
Food, Beverages and Tobacco	0.29%	0.66%
Textiles and Textile Products	2.46%	4.55%
Leather, Leather and Footwear	0.92%	1.74%
Wood and Products of Wood and Cork	0.49%	1.00%
Pulp, Paper, Paper , Printing and Publishing	0.38%	0.91%
Coke, Refined Petroleum and Nuclear Fuel	0.19%	0.42%
Chemicals and Chemical Products	0.64%	1.41%
Rubber and Plastics	0.81%	1.84%
Other Non-Metallic Mineral	0.46%	1.04%
Basic Metals and Fabricated Metal	0.69%	1.27%
Machinery, Nec	1.03%	2.39%
Electrical and Optical Equipment	3.63%	7.15%
Transport Equipment	0.84%	1.92%
Manufacturing, Nec; Recycling	0.89%	1.82%
Electricity, Gas and Water Supply	0.35%	0.72%
Construction	0.56%	1.24%
Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	0.44%	1.10%
Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	0.58%	1.34%
Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	0.44%	1.11%
Hotels and Restaurants	0.25%	0.60%
Inland Transport	0.39%	0.88%
Water Transport	0.92%	2.24%
Air Transport	0.94%	2.44%
Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	0.56%	1.36%
Post and Telecommunications	1.11%	2.74%
Financial Intermediation	0.22%	0.64%
Real Estate Activities	0.25%	0.74%
Renting of M&Eq and Other Business Activities	0.48%	1.20%
Public Admin and Defence; Compulsory Social Security	0.76%	1.84%
Education	0.47%	1.10%
Health and Social Work	0.54%	1.40%
Other Community, Social and Personal Services	0.58%	1.43%

From Figure 2 we can see that, for all sectors analysed, the proportion of intermediate goods sourced from China is quite low, however in all sectors the proportion of Chinese inputs (relative to total inputs) is increasing. In the majority of sectors analysed the proportion of production inputs sourced from China has more than doubled from 2005 to 2009. This is true for both "clean" industries, such as much of the services sector, and for "dirty" industries such mining and quarrying, and the production of chemical products. Overall this had led to an increase in the proportion of "embodied" emissions entering the EU production process from China, despite the declining emission intensity of the Chinese economy.

For some sectors the increase is not particularly large in relative terms, however in absolute terms it can be significant. Looking at the sector producing "other non-metallic mineral products", imports of emissions embodied in intermediates increased by 52%. However, looking at the increase in the absolute quantity of embodied CO_2 from this sector, it increased by over 1,000 ktCO_2 . For other sectors the increase in embodied emissions from intermediates is large both in relative and absolute terms. The sector supplying electricity, gas and water experienced an increase in embodied emissions in intermediates of 97% from 2005 to 2009. This near doubling translates to an additional 13,000 $ktCO_2$ embodied in the intermediate goods imported from China and used by this sector.

While Figure 2 shows that there has been a rise in the imported Chinese intermediates in all sectors from 2005 to 2009, it also shows that this pattern is not particularly notable in the sectors covered by the ETS. This could be indicative of the low price of ETS allowances since they have been introduced, which has been partially driven by an excess supply of ETS allowances (Granados and Carpintero (2013) and Anderson and DiMaria (2011)). The fact that the increase in intermediates imported from China is not higher in the sectors covered by the ETS indicates that for European firms other costs, such as the costs of energy, raw materials and labour, are more important than the costs of pollution when making production decisions. Table 9 below shows the value of intermediate inputs imported into the EU production process from China in 2005 and 2009. All sectors saw an increase over the period. The highest growth was seen in the "Electricity, Gas and Water Supply" sector, which saw the proportion of inputs sources from China grow by, on average, 30% per annum over the period.

Table 9: Chinese Intermediate goods used in the EU production process (million $)

	2005	2009	Annual % change
Mining and Quarying	292	721	25.37
Pulp, Paper, Paper, Printing and Publishing	1138	2864	25.96
Coke, Refined Petroleum and Nuclear Fuel	624	1664	27.78
Chemicals and Chemical Products	3053	7799	26.42
Other Non-Metallic Minerals	731	1753	24.45
Basic Metals and Fabricated Metal	4174	8752	20.34
Electricity, Gas and Water Supply	1365	3885	29.89
Other sectors (average)	2939	7653	27.03

5.3 Effect of emission pricing in China

As a final part of our analysis we simulate an increase in a hypothetical carbon price in China, using equation 8. The simulation carried out for China is a replication of that which was carried out for the EU; we look at the effect of increasing the price of emission allowances from \$17 to \$25 per tCO_2 in 2005 and 2009. We assume that the hypothetical emission price in China is only levied on those sectors regulated under the EU-ETS (see Table 2). The following table summarizes the effects of this price increase on the costs of the Chinese economy:

Table 10: Final price change after the variation of ETS price, China (2005, 2009)

	2005	2009	Δ
ETS sectors			
Mining and Quarrying	1.98%	1.30%	-0.68%
Pulp, Paper, Printing and Publishing	1.37%	0.90%	-0.46%
Coke, Refined Petroleum and Nuclear Fuel	1.73%	1.04%	-0.69%
Chemicals and Chemical Products	2.15%	1.32%	-0.82%
Other Non-Metallic Minerals	4.34%	2.72%	-1.62%
Basic Metals and Fabricated Metal	2.77%	1.53%	-1.24%
Electricity, Gas and Water Supply	11.80%	8.27%	-3.53%
Transport			
Other Inland Transport	0.74%	0.43%	-0.31%
Other Water Transport	0.66%	0.39%	-0.28%
Other Air Transport	0.81%	0.50%	-0.31%
Other sectors (average)	0.71%	0.42%	-0.29%

Table 10 shows that an increase in the hypothetical carbon price in China mainly affects the costs of the Electricity and the Non-Metallic Mineral sectors, as these sectors are among the most emission-intensive sectors of the Chinese economy. The emission intensity of all productive sectors in China falls from 2005 to 2009, so the impact of increasing the hypothetical carbon price is lower in 2009 than 2005, as the effect of the price is directly proportional to the emission content of each sector of the economy.

As for the European case, Equation 8 allows us to impose the carbon price directly on the seven sectors given in Table 2 and analyse the effects on the cost of these sectors and all other sectors through the input-output decomposition. The last row of Table 10 shows that the rise of the hypothetical emissions price generates only a minor increase in the costs of the non-ETS sectors in China.

Compared to the results for Europe, shown in Table 8, increasing the costs of the allowances has a larger effect on all sectors in China. This reflects the high emission intensity that characterises the Chinese economy.

If we compare the simulated price increase in China to the same increase in Eastern-EU countries, which were the most strongly affected by the simulated carbon price increase in the EU, the results for the Chinese economy are striking. For Eastern-EU countries increasing the ETS price from \$17 to \$25 caused the costs to rise by the 4.61% in 2005 and by the 2.65 % in 2009 in the Electricity and Gas sector. In China, the same rise in the emission price causes the costs of the same sector to increase by 11.80% and 8% in 2005 and 2009, respectively.

6 Conclusions

In this paper we analysed the patterns of CO_2 emissions in Europe both through statistical indicators and through an input-output methodology. Our results show that emissions, in absolute terms, have decreased across Europe from 2005 to 2009. At the same time, our analysis highlights that the patterns of emission intensity (calculated as the ratio of each country's sectoral emissions to GDP) are very different across the EU.

We found that the emission intensity decreased more rapidly in Eastern European countries, compared to ther rest of the EU. Our analysis shows that the abatement of CO_2 emissions in these countries is mainly due to the reduction of emissions in the most emission-intensive sectors, which are regulated under ETS. In order to disentangle the causes of the emission reduction, we analysed the output intensities and found that in the Eastern European countries the output of the emission-intensive sectors has decreased along with total emissions. Therefore, our analysis suggests that output from the more CO_2-intensive sectors, which are more important to the economies of Eastern EU countries relative to the rest of the EU, has decreased from 2005 to 2009. This result suggests that the relocation of the production of these sectors out of Europe may have played an important role in the reduction of the emission-intensity of the European production process.

We also investigated the dynamics of exports, in order to find what proportion of emission-intensive goods is produced for export. We find that in Eastern Europe a higher proportion of goods are produced by the ETS-sectors for export, compared to other regions of Europe. We also find that in this region the proportion of goods produced for export in the more CO_2-intensive sectors is increasing over the period analysed, which contrasts with the rest of Europe. As the UNFCC methodology assigns responsibility for emissions to the producer, rather than to the consumer, of emission-intensive goods, countries in this region will be penalised for these emissions which are driven by demand from abroad. Taxation of emissions based on production may be ineffective in reducing the demand for goods with high levels of embodied emissions.

Following Tarancon et al. (2010), we used an input-output price model to simulate the effect that a rise in the price of EU-ETS allowances, from \$17 to \$25/tonne, would have on the final price of goods in each EU country and sector in both 2005 and 2009. We find that all countries in the EU are reducing the emission-intensity of their production processes over the period, and that the reduction is greatest in those sectors regulated under the ETS. Eastern EU countries are the most strongly affected by the simulated price increase as their emission levels are the highest in Europe.

Finally, in order to investigate whether the reduction of European emission and output intensity from 2005 to 2009 was associated with a shift in the production of emission-intensive goods from European to non-European countries we examine how imports of intermediate goods into the EU from China have evolved over the period. Our results show that while emissions embodied in imported intermediates have increased from 2005 to 2009, this increase is not limited to, nor particularly notable in, the sectors regulated by the ETS.

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